

Cosmic Ray Backgrounds in an LBNE Far Detector on the surface

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Abstract

A surface Liquid Argon Far Detector for LBNE has formidable background issues from cosmic rays. There is no evidence they can be overcome.

1 Introduction

The far detector technology for LBNE is a liquid Argon TPC. For cost reasons, a surface detector is being considered by the LBNE reconfiguration process. For a repetition rate of 1.33 seconds for $1.7 \cdot 10^7$ s per year, there are $1.31 \cdot 10^7$ spills per year of 10 microseconds each or 131 seconds of live time per year. With a surface cosmic ray rate of approximately $100 \mu/(m^2s)$, and a surface area $24 \text{ m} \times 49 \text{ m}$, there are 15M μ per year entering through the top plus approximately another 15% entering the sides, or 18M per year total in the 131 s.

With a drift time of 4 ms, there are thus 7.1B muons during drift times associated with beam spills.¹ In contrast, the signal is 170 events per year for a 34 kT detector at Ash River.

A previous note looked at the qualitative issues associated with a liquid Argon Far Detector on the surface.[1] It identified four possible issues related to cosmic rays: *i.) they could generate so much data that the DAQ is overwhelmed, ii.) they might obscure such a large fraction of the volume of the detector that they overlap the events of interest to the point where the events cannot be reconstructed accurately, iii.) they might overwhelm the reconstruction and analysis such that the computing time required simply to remove the cosmic rays from the analysis is prohibitive, iv.) they could generate interactions in the argon which mimic the neutrino events of interest.* We only consider item (iv) and do not address the others in this note. There is an intuitive feeling among many that this will not be a problem despite the huge muon rate. At near detectors or short-baseline detectors, muons have not been a problem. However the requirements on signal to background are vastly different due to the larger signal rates at near detectors. A different argument can be found in Reference 1, “It is indeed highly unlikely that any muon with sufficient energy to produce a background event will be missed.” We question that statement for two reasons:

1. It is possible for muons to miss the active part of the detector, but to make other neutral particles which enter the detector and mimic a background event. This is particularly true for a modular detector with gaps and/or dead areas.
2. It is possible to see the muon and to fail to have enough information to unambiguously reject the background event. Some showers near muons (from bremsstrahlung, decay-in-flight, neutral hadrons from spallation, ...) will need to be cut.

¹We assume there are no photon counters. With 100% efficient photon counters, the effective overlap time would approach the beam spill length.

To fully determine these backgrounds, we either need sophisticated Monte Carlos or surface background measurements in an identical detector, together with full pattern recognition algorithms for the signal electron neutrinos. Because cosmic ray muons near the surface tend to be associated with showers, there can be pathological events with complex topologies which are hard to model.

One simple calculation that we can do is to find the efficiency for retaining signal ν_e events if we have to make a cut as a function of distance of closest approach between a ν_e vertex and the closest cosmic ray muon. (This is one of many possible ways to remove μ induced background.) We imagine a cylinder around the muon with a radius r . We might choose to cut any event, for example, within 3 radiation lengths of the muon. Our cosmic ray muon rate can be written:

$$100\mu(m^2s)^{-1} = 1\mu[\pi(90\text{ cm})^2 \times (4ms)]^{-1} \quad (1)$$

which implies that on average, there is a muon somewhere within a circle with a radius of 90 cm from every signal event. If we make a distance cut r from the vertex, the efficiency is

$$\epsilon \sim 1 - (\pi r^2)/(\pi(90\text{ cm})^2) \quad (2)$$

If we cut within 9 cm of each muon, this is 99% efficient. If we have to cut within 3 radiation lengths ($3 \times 14\text{ cm}$) the efficiency would be 78%. If we choose 2 collision lengths, ($2 \times 55\text{ cm}$), the efficiency is effectively zero.

2 Discussion and Summary

The background from these drifting muons is reduced as the detector is made modular and the drift distance decreases. But this increases the background from unseen muons.

Any backgrounds associated with the muons are likely strongly falling functions of shower energy. This makes them relatively a larger problem at Homestake where power for mass hierarchy and CP tests comes from lower energy electrons.

In NOvA, the pattern recognition for electron showers is not as powerful as in a liquid Argon detector. However the background starts out a factor of 400 lower, due to the drift time. The radius in equation 1 for the 10 μs spill is 18 m. There is a plan to measure potential cosmic ray backgrounds in NOvA using the Near Detector on the Surface.[2]

We conclude that it is not clear whether a Liquid Argon TPC on the surface for the beam physics goals of LBNE would have acceptable or unacceptable backgrounds. There are reasons for concern which have not been addressed.

References

- [1] D. Gerstle and S. Pordes, "Cosmic Ray Rates on the Surface for a Liquid Argon TPC", August 2006, now LBNE docdb-5950.
- [2] M. D'Agostino et al., "Cosmic Ray Backgrounds in the NOvA Far Detector", March 2010, NOvA docdb-4647